US008341930B1

(12) **United States Patent**
Chou et al.

(10) **Patent No.: US 8,341,930 B1**
(45) **Date of Patent: *Jan. 1, 2013**

(54) **ROPE STRUCTURE WITH IMPROVED BENDING FATIGUE AND ABRASION RESISTANCE CHARACTERISTICS**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 276 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **12/776,958**

(22) Filed: **May 10, 2010**

Related U.S. Application Data

(63) Continuation-in-part of application No. 11/522,236, filed on Sep. 14, 2006, now Pat. No. 7,739,863.

(60) Provisional application No. 60/717,627, filed on Sep. 15, 2005.

(51) **Int. Cl.**
D02G 3/36 (2006.01)

(52) **U.S. Cl.** **57/237**; 57/241; 57/258

(58) **Field of Classification Search** 57/223, 57/237, 241, 258
See application file for complete search history.

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(57) **ABSTRACT**

A rope structure adapted to engage an external structure comprising a primary strength component and a coating. The primary strength component comprises a plurality of fibers. The coating comprises a lubricant portion and a binder portion that fixes the lubricant portion relative to at least some of the fibers. The coating is applied to the primary strength component such that the lubricant portion reduces friction between adjacent fibers and reduces friction between fibers and the external structure.

18 Claims, 4 Drawing Sheets

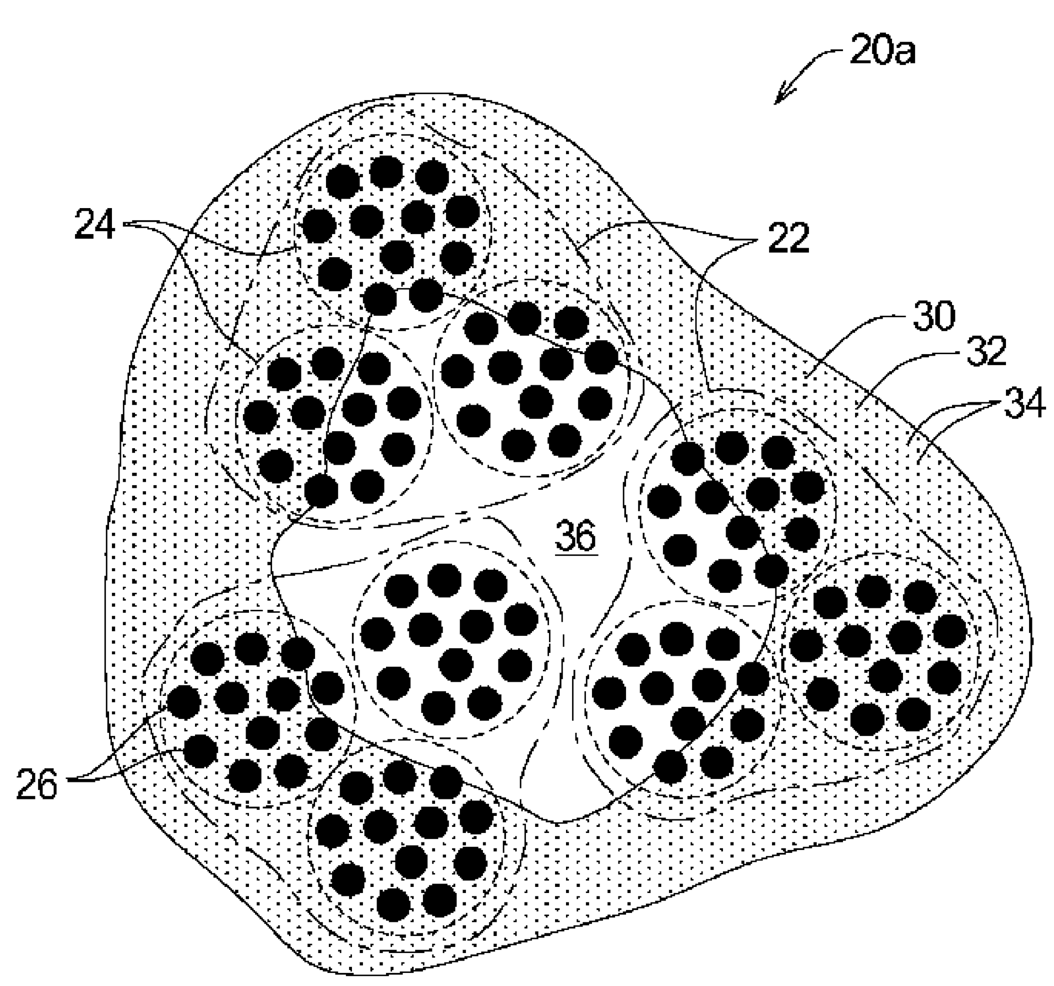

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FIG. 1A

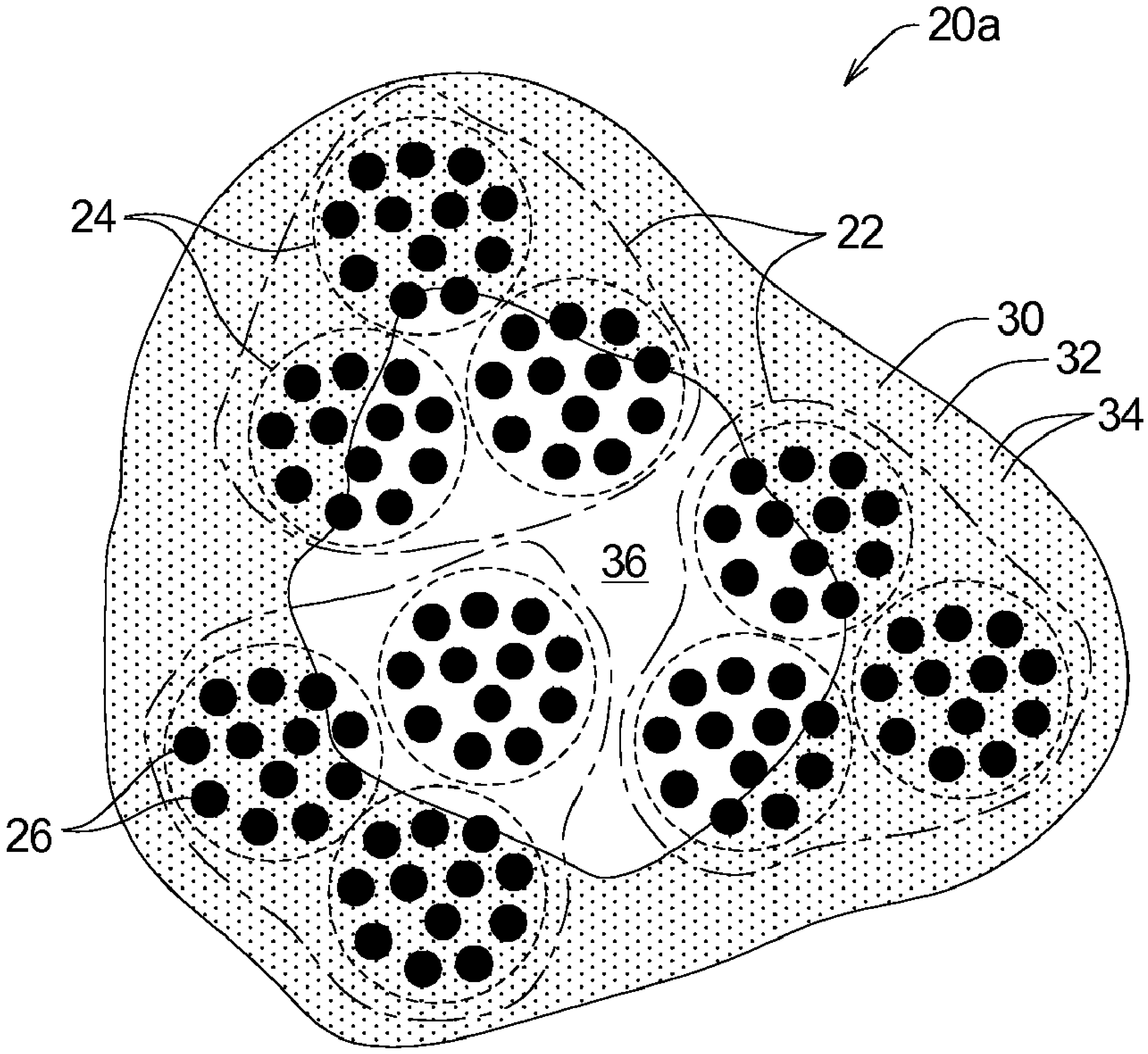


FIG. 1B

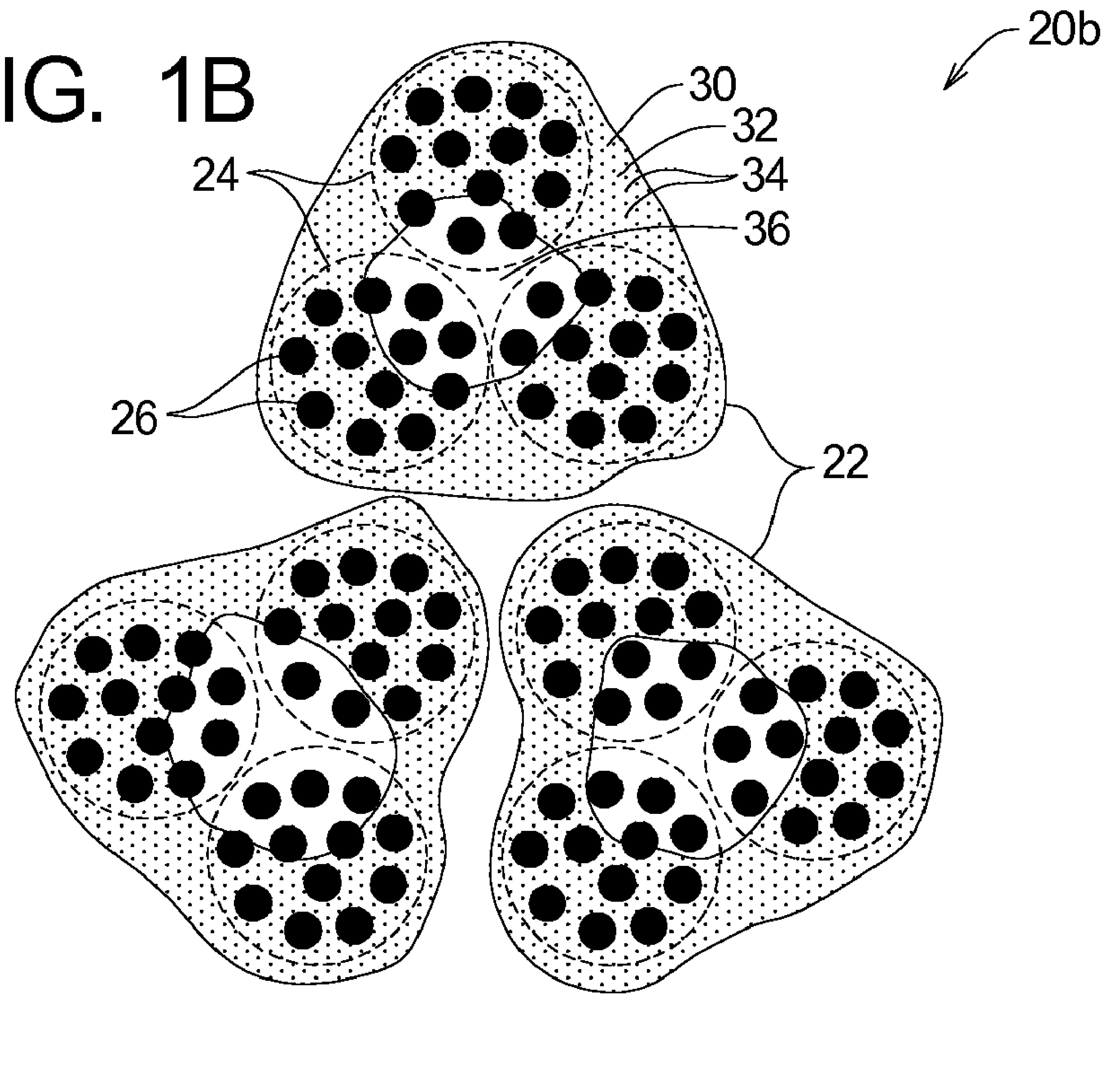


FIG. 2

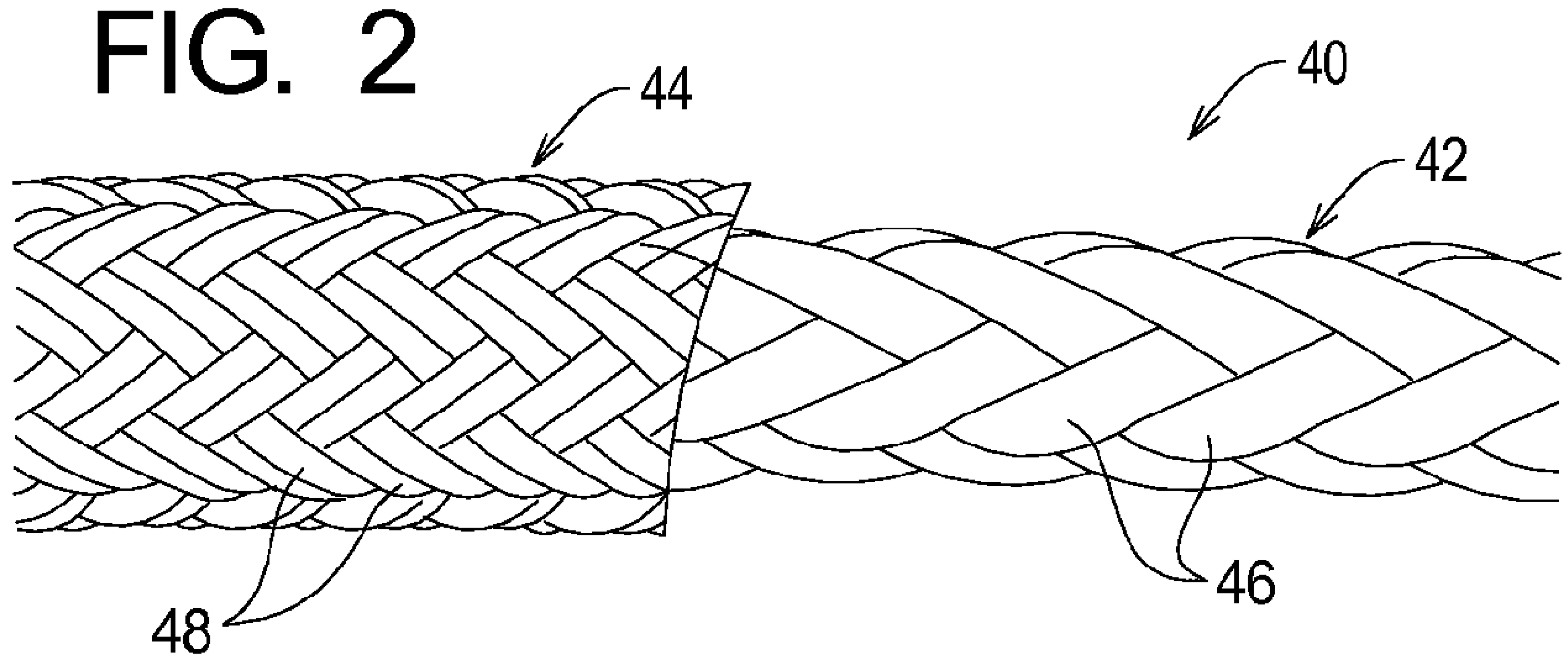


FIG. 3

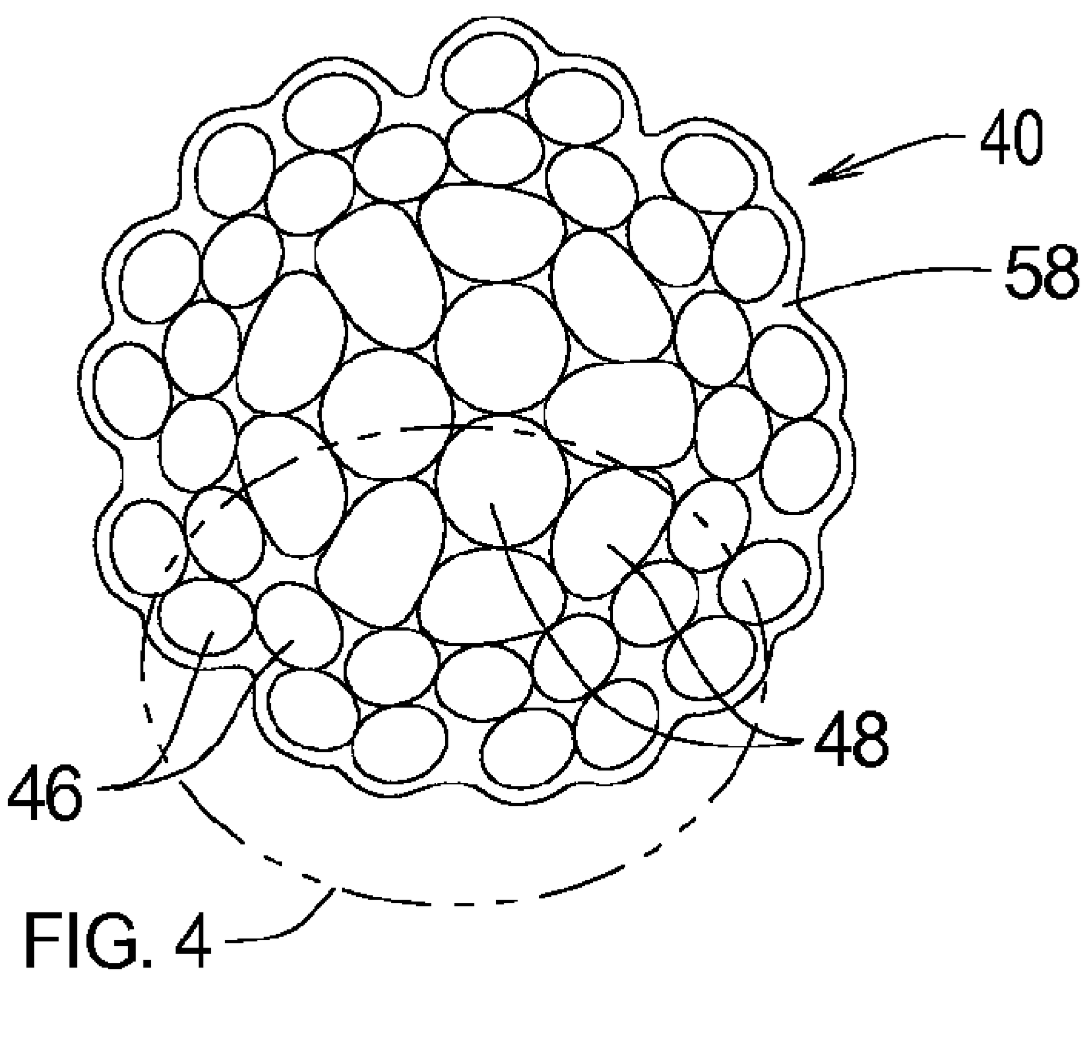


FIG. 4

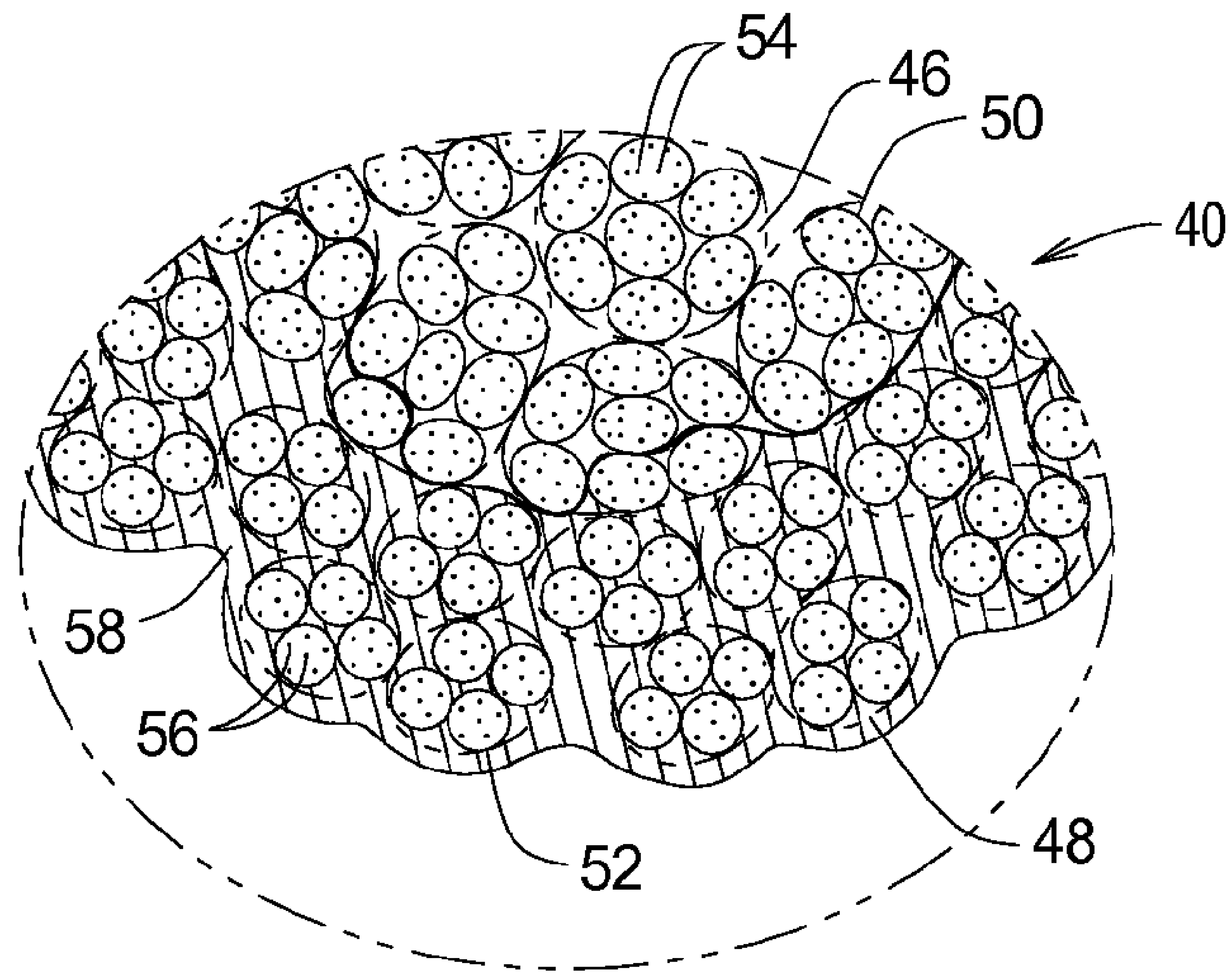


FIG. 5

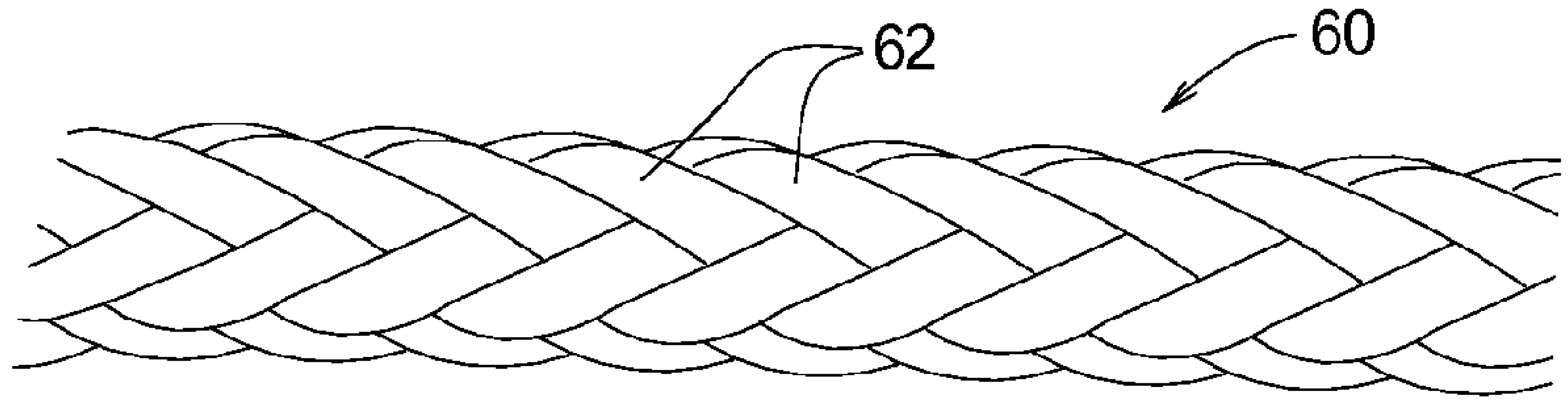


FIG. 6

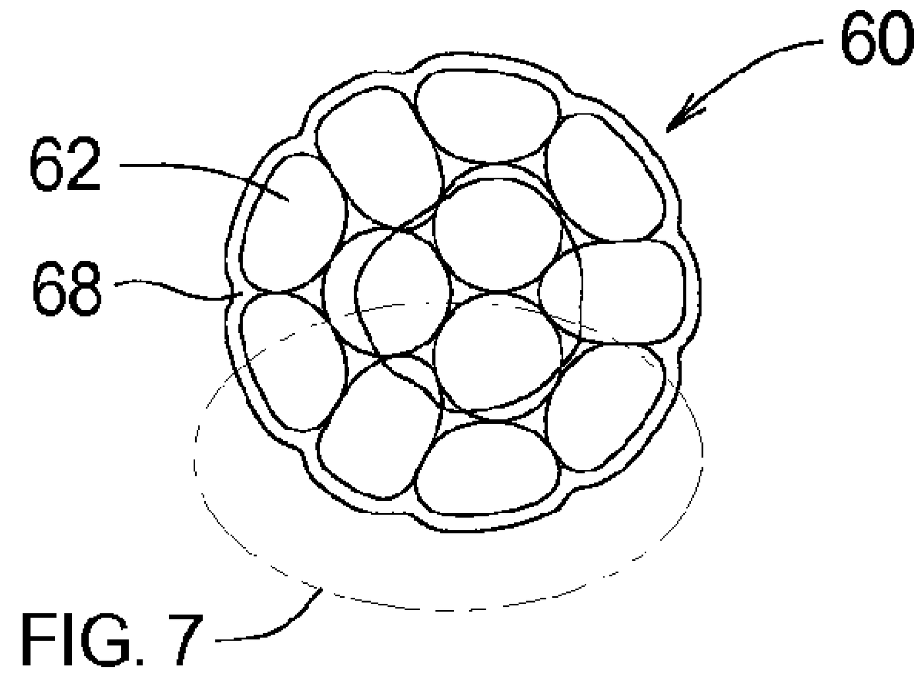


FIG. 7

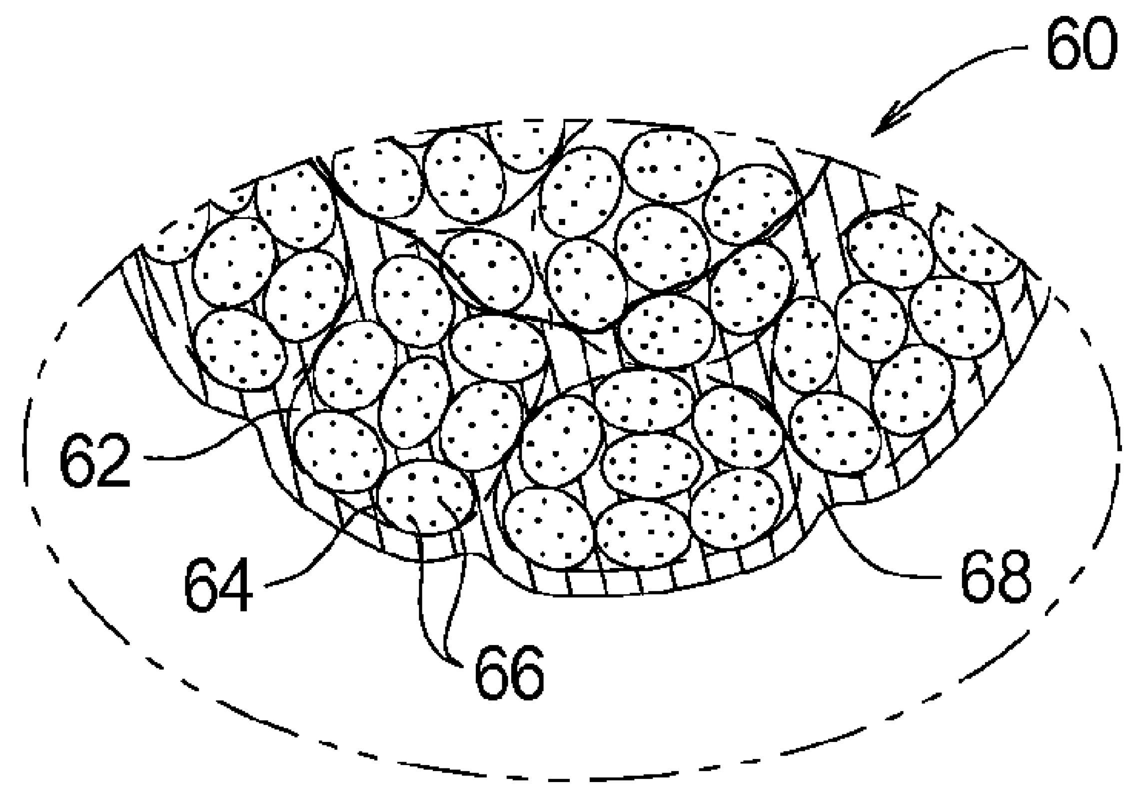


FIG. 8

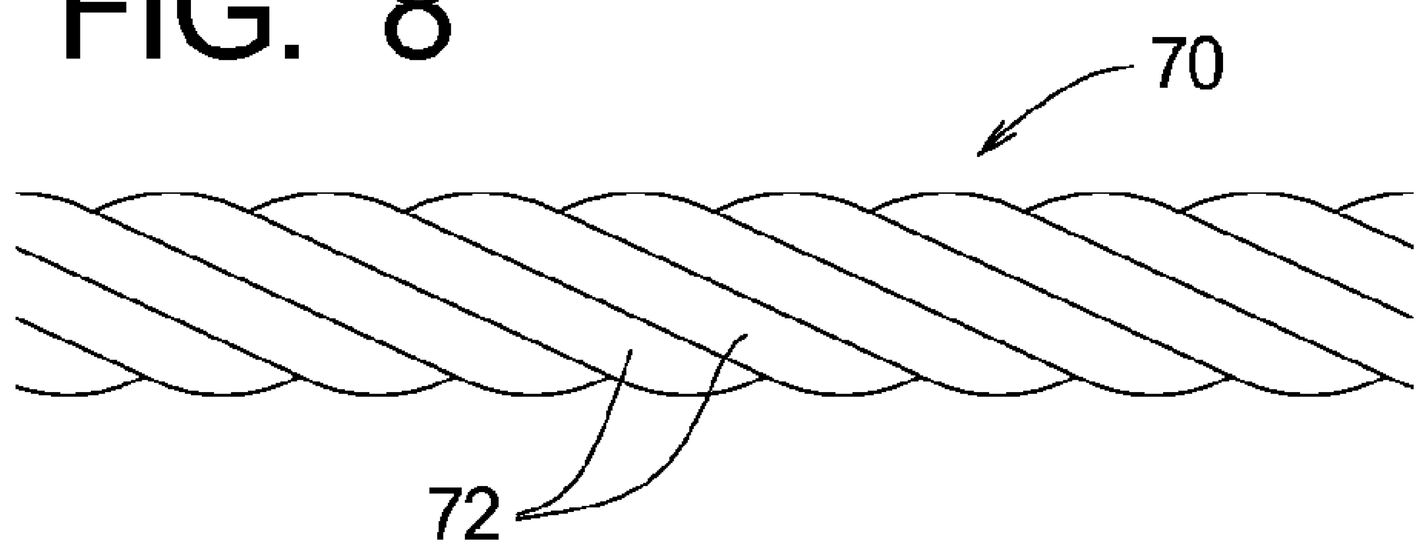


FIG. 9

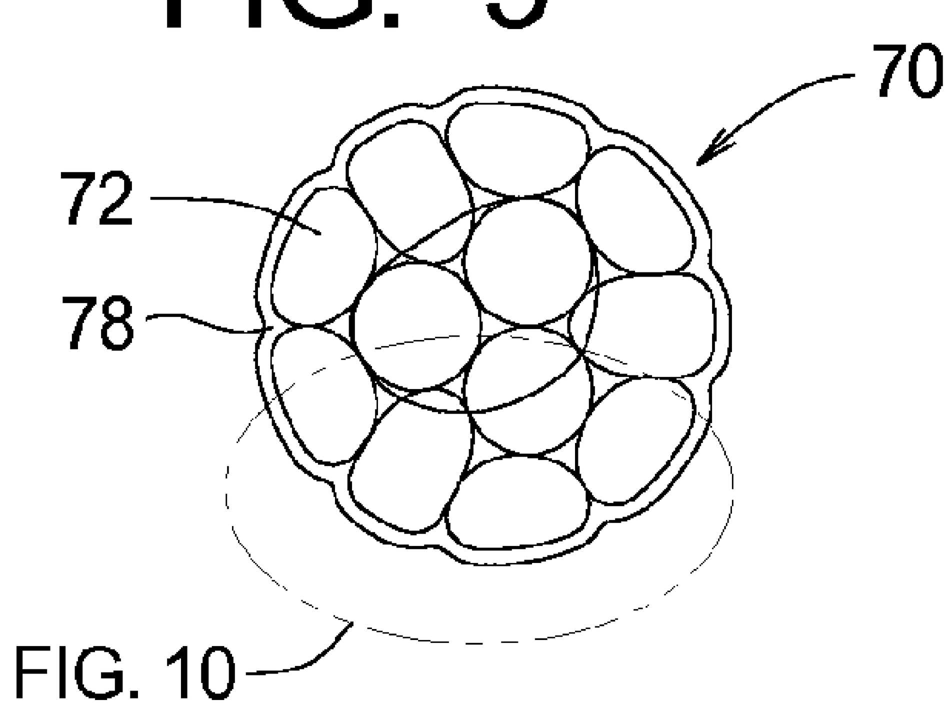


FIG. 10

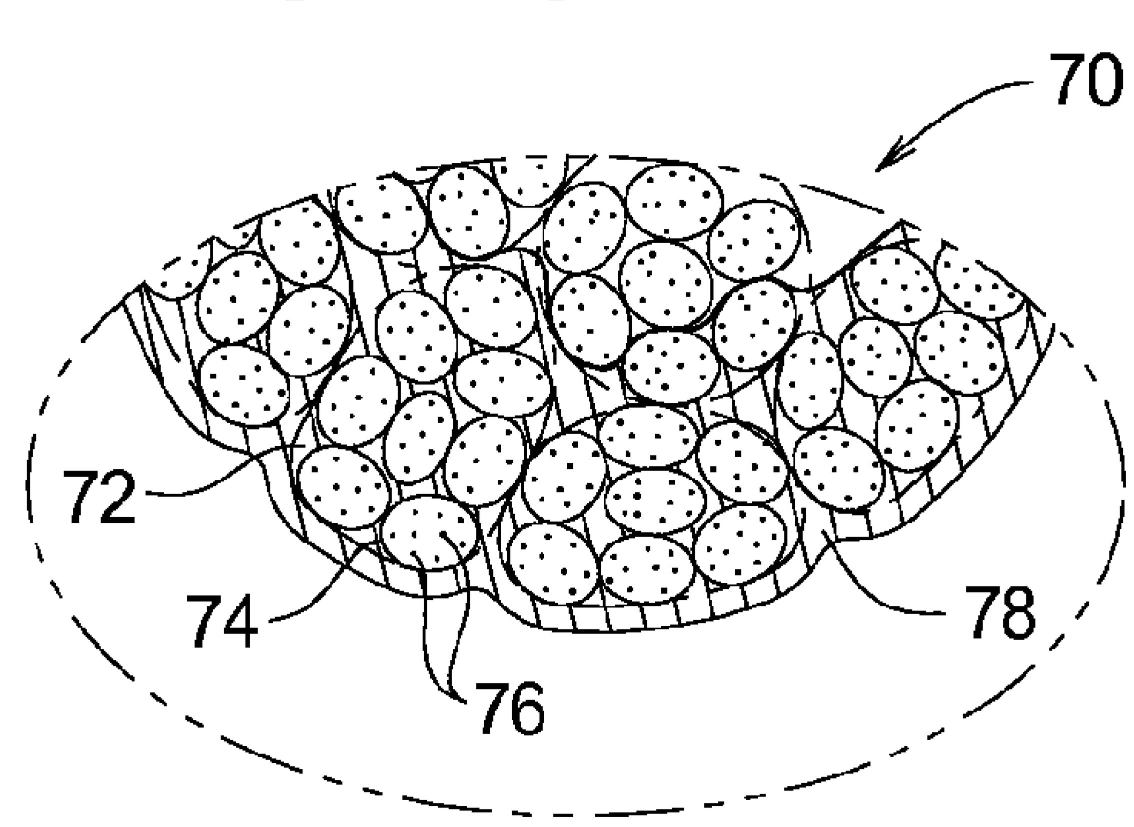


FIG. 11

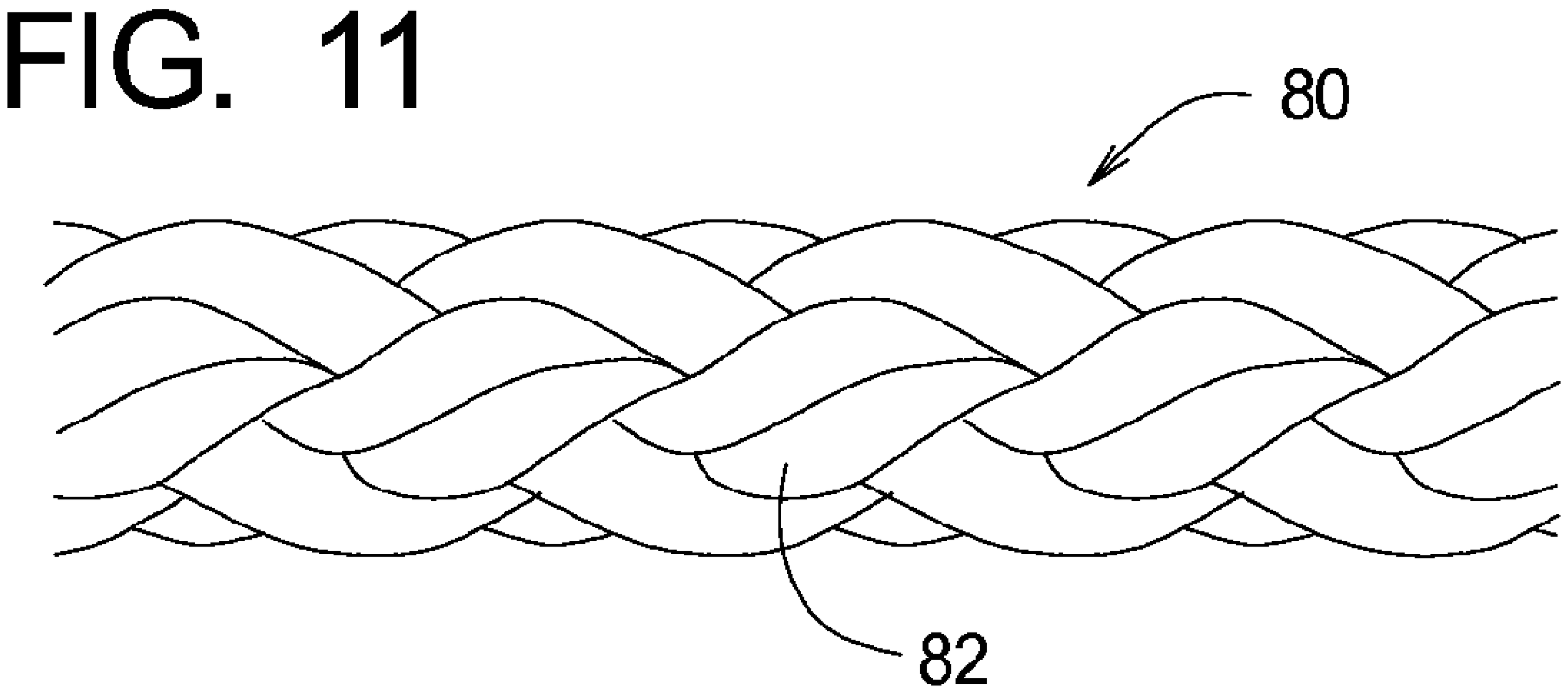


FIG. 12

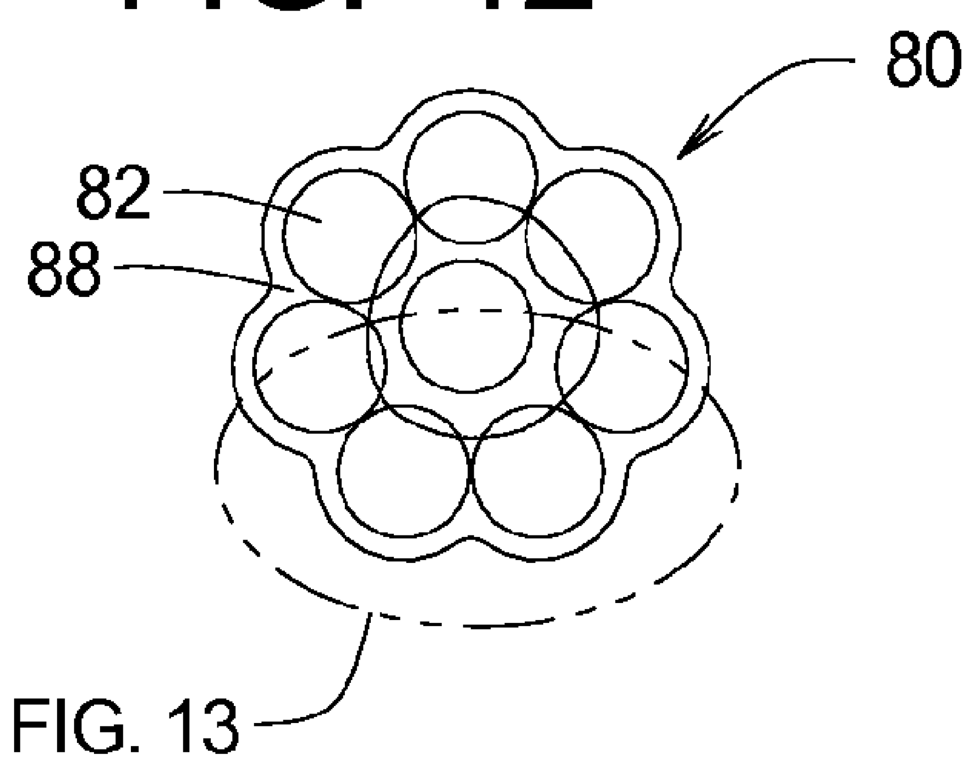
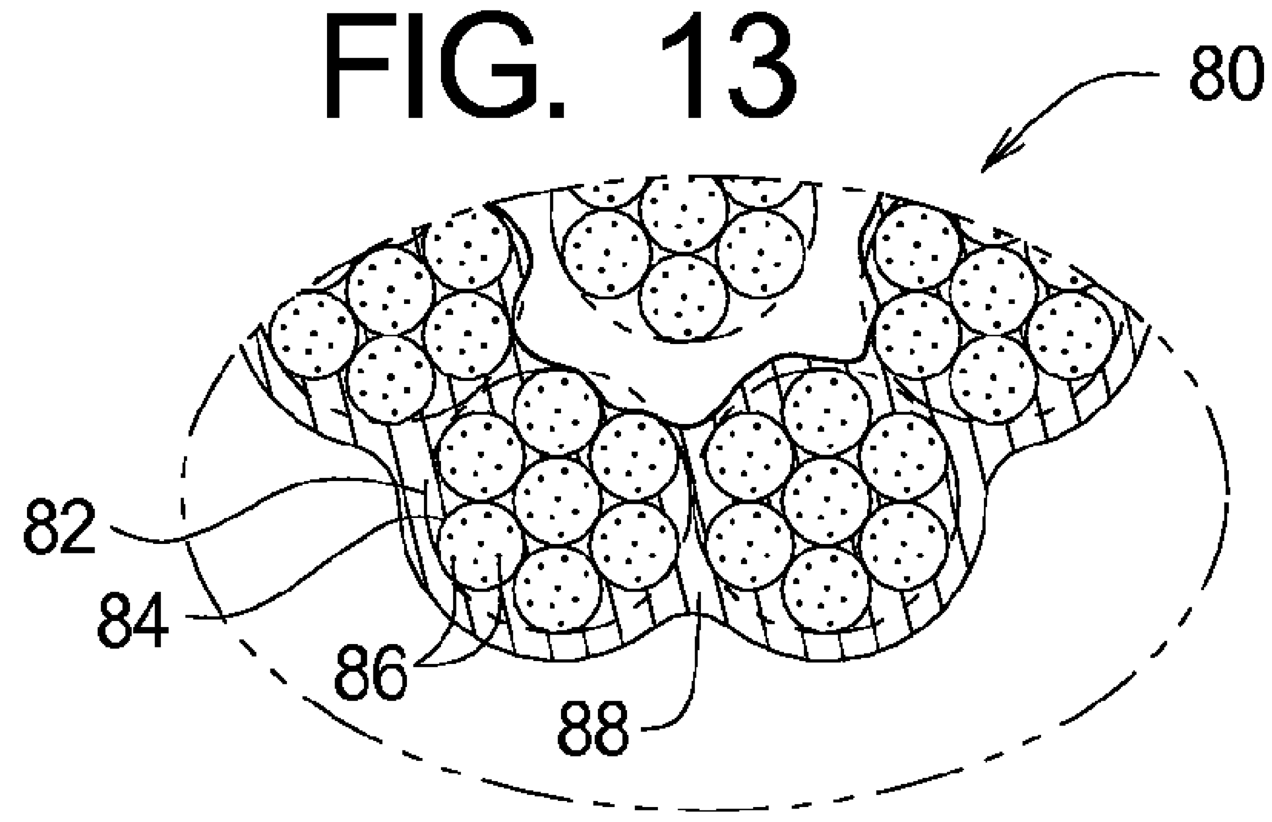


FIG. 13



ROPE STRUCTURE WITH IMPROVED BENDING FATIGUE AND ABRASION RESISTANCE CHARACTERISTICS

RELATED APPLICATIONS

This application, U.S. patent application Ser. No. 12/776,958, is a continuation-in-part of U.S. patent application Ser. No. 11/522,236 filed Sep. 14, 2006, now U.S. Pat. No. 7,739,863, which issued on Jun. 22, 2010.

U.S. patent application Ser. No. 11/522,236 claims benefit of U.S. Provisional Patent Application Ser. No. 60/717,627 filed Sep. 15, 2005.

The subject matter of the foregoing related applications are incorporated herein by reference.

TECHNICAL FIELD

The present invention relates to rope systems and methods and, in particular, to ropes that are coated to improve the resistance of the rope to bending fatigue.

BACKGROUND

The characteristics of a given type of rope determine whether that type of rope is suitable for a specific intended use. Rope characteristics include breaking strength, elongation, flexibility, weight, bending fatigue resistance and surface characteristics such as abrasion resistance and coefficient of friction. The intended use of a rope will determine the acceptable range for each characteristic of the rope. The term "failure" as applied to rope will be used herein to refer to a rope being subjected to conditions beyond the acceptable range associated with at least one rope characteristic.

The present invention relates to ropes that are commonly referred to in the industry as "lift lines". Lift lines are used to deploy (lower) or lift (raise) submersible equipment used for deep water exploration. Bending fatigue and abrasion resistance characteristics are highly important in the context of lift lines.

In particular, a length of lift line is connected at a first end to an on-board winch or capstan and at a second end to the submersible equipment. Between the winch and the submersible equipment, the lift line passes over or is wrapped around one or more intermediate structural members such as a closed chock, roller chock, bollard or bit, staple, bullnose, cleat, a heave compensating device, or a constant tensioning device.

When loads are applied to the lifting line, the lifting line wraps around such intermediate structural members and is thus subjected to bending fatigue and abrasion at the intermediate structural members. Abrasion and heat generated by friction at the point of contact between the lifting line and the intermediate structural members can create wear on the lifting line that can affect the performance of the lifting line and possibly lead to failure thereof.

The need thus exists for improved ropes for use as lifting lines that have improved bending fatigue and abrasion resistance characteristics.

SUMMARY

The present invention may be embodied as a rope structure adapted to engage an external structure comprising a primary strength component and a coating. The primary strength component comprises a plurality of fibers. The coating comprises a lubricant portion and a binder portion that fixes the lubricant portion relative to at least some of the fibers. The coating is applied to the primary strength component such that the lubricant portion reduces friction between adjacent fibers and reduces friction between fibers and the external structure.

The present invention may also be embodied as a method of forming a rope structure adapted to engage an external structure comprising the following steps. A plurality of fibers is provided. The plurality of fibers is combined to form a primary strength component. A coating material comprising a lubricant portion and a binder portion is provided in liquid form. The coating material is applied in liquid form to the primary strength component. The coating material in liquid form is allowed to dry on the primary strength member to form a coating such that the lubricant portion is adhered to at least some of the fibers to reduce friction between adjacent fibers and to reduce friction between fibers and the external structure.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic cut-away view of a rope constructed in accordance with, and embodying, the principles of the present invention;

FIG. **2** is a side elevation view of a first example of a rope of the present invention;

FIG. **3** is a radial cross-section of the rope depicted in FIG. **2**;

FIG. **4** is a close-up view of a portion of FIG. **3**;

FIG. **5** is a side elevation view of a second example of a rope of the present invention;

FIG. **6** is a radial cross-section of the rope depicted in FIG. **5**;

FIG. **7** is a close-up view of a portion of FIG. **6**;

FIG. **8** is a side elevation view of a third example of a rope of the present invention;

FIG. **9** is a radial cross-section of the rope depicted in FIG. **8**;

FIG. **10** is a close-up view of a portion of FIG. **9**;

FIG. **11** is a side elevation view of a fourth example of a rope of the present invention;

FIG. **12** is a radial cross-section of the rope depicted in FIG. **8**; and

FIG. **13** is a close-up view of a portion of FIG. **12**.

DETAILED DESCRIPTION

Referring initially to FIGS. **1**A and **1**B of the drawing, depicted in cross-section therein are rope structures **20**_a_ and **20**_b_ constructed in accordance with, and embodying, the principles of the present invention. The rope structures **20**_a_ and **20**_b_ are each formed by one or more plys or strands **22**. The plys or strands **22** are formed by one or more yarns **24**. The yarns **24** are formed by a plurality of fibers **26**. By way of example, the fibers **26** may be twisted together to form the yarns, the yarns **24** twisted to form the plys or to strands **22**, and the strands **22** braided or twisted to form the rope structure **20**_a_ or **20**_b_.

In addition, the example rope structures **20**_a_ and **20**_b_ each comprises a coating **30** that is applied either to the entire rope structure (FIG. **1**A) or to the individual strands (FIG. **1**B). In the example ropes **20**_a_ and **20**_b_, coating material is applied in liquid form and then allowed to dry to form the coating **30**. The coating **30** comprises a binder portion **32** (solid matrix) and a lubricant portion **34** (e.g., suspended particles). The binder portion **32** adheres to or suspends the fibers **26** to hold the lubricant portion **34** in place adjacent to the fibers **26**. More specifically, the coating **30** forms a layer around at least some of the fibers **26** that arranges the lubricant portion **34** between at least some of the adjacent fibers **26** and between the fibers **26** and any external structural members in contact with the rope structure **20***a* or **20***b*.

The fibers **26** are combined to form the primary strength component of the rope structures **20***a* and **20***b*. The lubricant portion **34** of the coating **30** is supported by the binder portion to reduce friction between adjacent fibers **26** as well as between the fibers **26** and any external structural members in contact with the rope structure **20***a* or **20***b*. The lubricant portion **34** of the coating **30** thus reduces fatigue on the fibers **26** when the rope structures **20***a* or **20***b* are bent around external structures. Without the lubricant portion **34** of the coating **30**, the fibers **26** would abrade each other, increasing bending fatigue on the entire rope structure **20**. The lubricant portion **34** of the coating **30** further reduces friction between the fibers **26** and any external structural members, thereby increasing abrasion resistance of the rope structures **20***a* and **20***b*.

With the foregoing understanding of the basic construction and characteristics of the rope structure **20** of the present invention in mind, the details of construction and composition of the blended yarn **20** will now be described.

In the liquid form, the coating material comprises at least a carrier portion, the binder portion, and the lubricant portion. The carrier portion maintains the liquid form of the coating material in a flowable state. However, the carrier portion evaporates when the wet coating material is exposed to the air, leaving the binder portion and the lubricant portion to form the coating **30**. When the coating material has dried to form the coating **30**, the binder portion **32** adheres to the surfaces of at least some of the fibers **26**, and the lubricant portion **34** is held in place by the binder portion **32**. The coating material is solid but not rigid when dried as the coating **30**.

In the example rope structures **20***a* and **20***b*, the coating material is formed by a mixture comprising a base forming the carrier portion and binder portion and PolyTetraFluoro-Ethylene (PTFE) forming the lubricant portion. The base of the coating material is available from s.a. GOVI n.v. of Belgium under the tradename LAGO **45** and is commonly used as a coating material for rope structures. Alternative products that may be used as the base material include polyurethane dispersions; in any event, the base material should have the following properties: good adhesion to fiber, stickiness, soft, flexible. The base of the coating material is or may be conventional and will not be described herein in further detail.

The example lubricant portion **34** of the coating material is a solid material generically known as PTFE but is commonly referred to by the tradename Teflon. The PTFE used in the coating material of the example rope structures **20***a* and **20***b* is in powder form, although other forms may be used if available. The particle size of the PTFE should be within a first preferred range of approximately 0.10 to 0.50 microns on average but in any event should be within a second preferred range of 0.01 to 2.00 microns on average. The example rope structures **20***a* and **20***b* are formed by a PTFE available in the marketplace under the tradename PFTE30, which has an average particle size of approximately 0.22 microns.

The coating material used by the example rope structures **20***a* and **20***b* comprises PTFE within a first preferred range of approximately 32 to 37% by weight but in any event should be within a second preferred range of 5 to 40% by weight, with the balance being formed by the base. The example rope structures are formed by a coating material formed by approximately 35% by weight of the PTFE.

As an alternative to PTFE, the lubricant portion **34** may be formed by solids of other materials and/or by a liquid such as silicon oil. Other example materials that may form the lubricant portion **34** include graphite, silicon, molybdenum disulfide, tungsten disulfide, and other natural or synthetic oils. In any case, enough of the lubricant portion **34** should be used to yield an effect generally similar to that of the PTFE as described above.

The coating **26** is applied by dipping the entire rope structure **20***a* and/or individual strands **22** into or spraying the structure **20***a* and/or strands **22** with the liquid form of the coating material. The coating material is then allowed to dry on the strands **22** and/or rope structure **20***a*. If the coating **26** is applied to the entire rope structure **20***a*, the strands are braided or twisted before the coating material is applied. If the coating **26** is applied to the individual strands **22**, the strands are braided or twisted to form the rope structure **20***b* after the coating material has dried.

In either case, one or more voids **36** in the coating **30** may be formed by absences of coating material. Both dipping and spraying are typically done in a relatively high speed, continuous process that does not allow complete penetration of the coating material into the rope structures **20***a* and **20***b*. In the example rope structure **20***a*, a single void **36** is shown in FIG. **1**A, although this void **36** may not be continuous along the entire length of the rope structure **20***a*. In the example rope structure **20***b*, a void **36** is formed in each of the strands **22** forming the rope structure **20***b*. Again, the voids **36** formed in the strands **22** of the rope structure **20***b* need not be continuous along the entire length of the rope structure **20***a*.

In the example rope structures **20***a* and **20***b*, the matrix formed by the coating **30** does not extend through the entire volume defined by the rope structures **20***a* or **20***b*. In the example structures **20***a* and **20***b*, the coating **30** extends a first preferred range of approximately ¼ to ½ of the diameter of the rope structure **20***a* or the strands of the rope structure **20***b* but in any event should be within a second preferred range of approximately ⅛ to ¾ of the diameter of the rope structure **20***a* or the strands of the rope structure **20***b*. In the example rope structures **20***a* and **20***b*, the coating matrix extends through approximately ⅓ of the diameter of the rope structure **20***a* or the strands of the rope structure **20***b*.

In other embodiments, the matrix formed by the coating **30** may extend entirely through the entire diameter of rope structure **20***a* or through the entire diameter of the strands of the rope structure **20***b*. In these cases, the rope structure **20***a* or strands of the rope structure **20***b* may be soaked for a longer period of time in the liquid coating material. Alternatively, the liquid coating material may be forced into the rope structure **20***a* or strands of the rope structure **20***b* by applying a mechanical or fluid pressure.

The following discussion will describe several particular example ropes constructed in accordance with the principles of the present invention as generally discussed above.

First Specific Rope Example

Referring now to FIGS. **2**, **3**, and **4**, those figures depict a first specific example of a rope **40** constructed in accordance with the principles of the present invention. As shown in FIG. **2**, the rope **40** comprises a rope core **42** and a rope jacket **44**. FIG. **2** also shows that the rope core **42** and rope jacket **44** comprise a plurality of strands **46** and **48**, respectively. FIG. **4** shows that the strands **46** and **48** comprise a plurality of yarns **50** and **52** and that the yarns **50** and **52** in turn each comprise a plurality of fibers **54** and **56**, respectively. FIGS. **3** and **4** also show that the rope **40** further comprises a coating material **58** that forms a matrix that at least partially surrounds at least some of the fibers **54** and **56**.

The exemplary rope core **42** and rope jacket **44** are formed from the strands **46** and **48** using a braiding process. The example rope **40** is thus the type of rope referred to in the industry as a double-braided rope. The strands **46** and **48** may be substantially identical in size and composition. Similarly, the yarns **40** and **42** may also be substantially identical in size and composition. However, strands and yarns of different sizes and compositions may be combined to form the rope core **42** and rope jacket **44**. Additionally, the fibers **44** and **46** forming at least one of the yarns **40** and **42** may be of different types.

Second Rope Example

Referring now to FIGS. **5**, **6**, and **7**, those figures depict a second example of a rope **60** constructed in accordance with the principles of the present invention. As perhaps best shown in FIG. **6**, the rope **60** comprises a plurality of strands **62**. FIG. **7** further illustrates that each of the strands **62** comprises a plurality of yarns **64** and that the yarns **64** in turn comprise a plurality of fibers **66**. FIGS. **6** and **7** also show that the rope **60** further comprises a coating material **68** that forms a matrix that at least partially surrounds at least some of the fibers **66**.

The strands **62** are formed by combining the yarns **64** using any one of a number of processes. The exemplary rope **60** is formed from the strands **62** using a braiding process. The example rope **60** is thus the type of rope referred to in the industry as a braided rope.

The strands **62** and yarns **64** forming the rope **60** may be substantially identical in size and composition. However, strands and yarns of different sizes and compositions may be combined to form the rope **60**. In the example rope **60**, the strands **62** (and thus the rope **60**) may be 100% HMPE or a blend of 40-60% by weight of HMPE with the balance being Vectran.

Third Rope Example

Referring now to FIGS. **8**, **9**, and **10**, those figures depict a third example of a rope **70** constructed in accordance with the principles of the present invention. As perhaps best shown in FIG. **9**, the rope **70** comprises a plurality of strands **72**. FIG. **10** further illustrates that each of the strands **72** comprises a plurality of yarns **74**, respectively. The yarns **74** are in turn comprised of a plurality of fibers **76**. FIGS. **9** and **10** also show that the rope **70** further comprises a coating material **78** that forms a matrix that at least partially surrounds at least some of the fibers **76**.

The strands **72** are formed by combining the yarns **74** using any one of a number of processes. The exemplary rope **70** is formed from the strands **72** using a twisting process. The example rope **70** is thus the type of rope referred to in the industry as a twisted rope.

The strands **72** and yarns **74** forming the rope **70** may be substantially identical in size and composition. However, strands and yarns of different sizes and compositions may be combined to form the rope **70**.

Fourth Rope Example

Referring now to FIGS. **11**, **12**, and **13**, those figures depict a fourth example of a rope **80** constructed in accordance with the principles of the present invention. As perhaps best shown in FIG. **12**, the rope **80** comprises a plurality of strands **82**. FIG. **13** further illustrates that each of the strands **82** comprise a plurality of yarns **84** and that the yarns **84** in turn comprise a plurality of fibers **86**, respectively. FIGS. **12** and **13** also show that the rope **80** further comprises a coating material **88** that forms a matrix that at least partially surrounds at least some of the fibers **86**.

The strands **82** are formed by combining the yarns **84** using any one of a number of processes. The exemplary rope **80** is formed from the strands **82** using a braiding process. The example rope **80** is thus the type of rope commonly referred to in the industry as a braided rope.

The strands **82** and yarns **84** forming the rope **80** may be substantially identical in size and composition. However, strands and yarns of different sizes and compositions may be combined to form the rope **80**. The first and second types of fibers are combined to form at least some of the yarns **84** are different as described above with reference to the fibers **24** and **28**. In the example rope **80**, the strands **82** (and thus the rope **80**) may be 100% HMPE or a blend of 40-60% by weight of HMPE with the balance being Vectran.

Given the foregoing, it should be clear to one of ordinary skill in the art that the present invention may be embodied in other forms that fall within the scope of the present invention.

What is claimed is:

1. A rope structure adapted to engage an intermediate structure while loads are applied to ends of the rope structure, comprising:
- a primary strength component comprising a plurality of fibers adapted to bear the loads applied to the ends of the rope structure;
- a coating comprising
  - a lubricant portion formed by at least one of solids and liquids, and
  - a binder portion, where the binder portion is applied to the primary strength portion to form a matrix that at least partly surrounds at least some of the fibers to support the lubricant portion relative to at least some of the fibers; whereby
- the matrix supports the lubricant portion such that the lubricant portion
  - reduces friction between at least some of the plurality of fibers, and
  - reduces friction between at least some of the plurality of fibers and the intermediate structures;
- the coating material is applied to the primary strength component in liquid form and allowed to dry to form the coating; and
- the liquid form of the coating material comprises substantially between 32% and 37% by weight of the lubricant portion.

2. A rope structure as recited in claim **1**, in which the liquid form of the coating material comprises substantially between 5% and 40% by weight of the lubricant portion.

3. A rope structure as recited in claim **1**, in which the liquid form of the coating material comprises approximately 35% by weight of the lubricant portion.

4. A rope structure as recited in claim **1**, in which the binder portion adheres to the fibers such that the lubricant portion is arranged between at least some of the fibers and between at least some of the fibers and the intermediate structure.

5. A rope structure as recited in claim **4**, in which the lubricant portion is in powder form.

6. A rope structure as recited in claim **1**, in which the lubricant portion is formed by particles having an average size of within approximately 0.01 microns to 2.00 microns.

7. A rope structure as recited in claim **6**, in which an average size of the particles is within approximately 0.10 microns to 0.50 microns.

8. A rope structure as recited in claim **6**, in which an average size of the particles is approximately 0.22 microns.

9. A rope structure as recited in claim **1**, in which the binder portion adheres to at least some of the fibers.

10. A rope structure as recited in claim **1**, in which the coating comprises a polyurethane dispersion.

11. A method of forming a rope structure adapted to engage an intermediate structure while loads are applied to ends of the rope structure, comprising the steps of:

providing a plurality of fibers;

combining the plurality of fibers to form a primary strength component adapted to bear the loads applied to the ends of the rope structure;

providing a coating material in liquid form comprising a lubricant portion and a binder portion, where the lubricant portion is formed by at least one of particles, where an average particle size of the particles is within approximately 0.01 microns to 2.00 microns;

applying the coating material in liquid form to the primary strength component;

allowing the coating material in liquid form to dry on the primary strength member such that the binder portion forms a matrix that at least partly surrounds at least some of the fibers to support the lubricant portion relative to at least some of the fibers such that the lubricant portion reduces friction between at least some of the plurality of fibers and between at least some of the plurality of fibers and the intermediate structure.

12. A method as recited in claim **11**, in which the step of providing the liquid form of the coating material comprises the step of providing substantially between 5% and 40% by weight of the lubricant portion.

13. A method as recited in claim **11**, in which the step of providing the liquid form of the coating material comprises the step of providing a binder portion that adheres at least some of the fibers and holds the lubricant portion in place.

14. A method as recited in claim **11**, in which the step of providing the liquid form of the coating material comprises the step of providing a binder portion comprising a polyurethane dispersion.

15. A rope structure adapted to engage an intermediate structure while loads are applied to ends of the rope structure, comprising:

a primary strength component comprising a plurality of fibers adapted to bear the loads applied to the ends of the rope structure, where the plurality of fibers are combined to form plurality of yarns, the plurality of yarns are combined to form a plurality of strands, and the plurality of strands are combined to form the primary strength component;

a coating comprising particles suspended within a matrix formed of binder material such that the binder fixes the particles relative to at least some of the fibers such that the particles reduce friction between at least some of the plurality of fibers and between at least some of the plurality of fibers and the intermediate structure; wherein

the coating is formed by applying coating material in a liquid form to the primary strength component;

the liquid form of the coating material comprises substantially between 5% and 40% by weight of the lubricant portion; and

an average size of the particles is within approximately 0.01 microns to 2.00 microns.

16. A rope structure adapted to engage an intermediate structure while loads are applied to ends of the rope structure, comprising:

a primary strength component comprising a plurality of fibers adapted to bear the loads applied to the ends of the rope structure;

a coating comprising

a lubricant portion formed by at least one of solids and liquids, and

a binder portion, where the binder portion is applied to the primary strength portion to form a matrix that at least partly surrounds at least some of the fibers to support the lubricant portion relative to at least some of the fibers; whereby

the matrix supports the lubricant portion such that the lubricant portion

reduces friction between at least some of the plurality of fibers, and

reduces friction between at least some of the plurality of fibers and the intermediate structure; and

the lubricant portion is formed by particles having an average size of within approximately 0.01 microns to 2.00 microns.

17. A rope structure as recited in claim **16**, in which an average size of the particles is within approximately 0.10 microns to 0.50 microns.

18. A rope structure as recited in claim **16**, in which an average size of the particles is approximately 0.22 microns.

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